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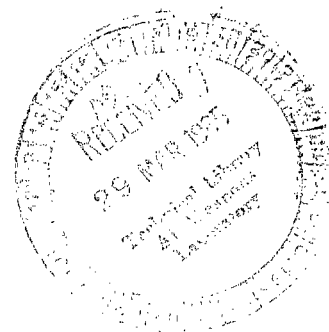
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SUMMARY

Three levels of total control power and three values of maximum stick travel were tested for the X-14A VTOL research aircraft. Airframe damping was also varied. Two NASA pilots evaluated the relative importance of these parameters as maneuvering requirements for a hovering VTOL aircraft. They rated total control power as having a predominant effect during visual hovering out-of-ground effect. Changing the control sensitivity (control power per inch of stick travel) had only a minor effect over the range of sensitivity investigated.

INTRODUCTION

The response of an aircraft to control inputs is of primary concern to the pilot during maneuvering flight. The amount of control moment required and the magnitude of the aircraft damping, two characteristics which influence the aircraft's response, have been studied for many years. With the advent of the vertical take-off and landing (VTOL) aircraft, the control requirement studies have been extended to this type of aircraft. The results of simulator studies are presented in reference 1, variable-stability helicopter results are presented in reference 2, and variable-stability VTOL airplane results are presented in reference 3.

In these previous studies changes were made in the total control power available, but the stick gearing remained constant; thus, the sensitivity (control power per inch of stick travel) was also changed. While it is realized that both the total control power available and the control sensitivity are significant factors affecting the pilot's rating of a vehicle's controllability, very little research has been conducted to resolve their relative significance. The present research program was undertaken to investigate the three factors affecting lateral control requirements based on pilot opinion (control power, control sensitivity, and damping) to determine their respective importance and perhaps the areas of operation where each term supplied the more meaningful criteria.

This report presents the results of a flight investigation conducted with the X-14A VTOL research vehicle in which a range of both lateral-control power and sensitivity were studied. The lateral axis was chosen for this study because previous studies (refs. 1, 2, and 3) indicated that control about this axis was the more critical from the standpoint of pilot opinion.

Two NASA test pilots participated in the program to determine the pilot opinion boundaries based upon systematic variations of control power, sensitivity, and airframe damping.

DESCRIPTION OF AIRPLANE

The results presented in this report were obtained from a flight investigation using the X-14A variable-stability and control VTOL test vehicle. The X-14A (fig. 1) is a fixed-wing, jet-propelled, vectored thrust aircraft. The exhaust from the jet engines passes through cascade-type diverters which allow the pilot to select vertical or horizontal thrust. During hover and low speed flight, control of the airplane attitude was maintained by the use of reaction jets at the wing tips and tail with air for these controls being bled from the compressor of the turbojet engines. A detailed description of the X-14A and its variable-stability and control system is presented in reference 3. During these tests the operational weight of the test vehicle was 3,700 pounds with a thrust-to-weight ratio available of 1.1 to 1.2.

In the present investigation the gearing in the lateral control system was modified to permit, through a ground adjustment, the selection of lateral stick travel of ± 4.5 , ± 3.5 , or ± 3.0 inches. These values were considered to be in the range of practical interest for jet lift VTOL aircraft. The installation of the mechanical system, which afforded this ability to vary the stick gearing, required a change in the original stick travel; thus, it was impossible to conduct tests with the ± 5 inches of stick travel used in reference 3. To alleviate any change in the friction and breakout force characteristics which normally would accompany these changes in stick travel, a hydraulic boost cylinder was installed in the lateral control system. The characteristics of this hydraulic system were such that a force of about $1/3$ to $1/2$ pound was required at the stick grip and no force gradient existed. The control moment and damping functions of the variable control system remained unchanged from that used in reference 3.

TESTS

This investigation was conducted during visual hovering, out-of-ground effect, and in generally calm wind conditions. The pilot opinion of the lateral control system was derived by performing rapid roll maneuvers to initiate or stop sideward velocity and by noting the aircraft response to rapid control reversals as well as an evaluation of the ability to hover precisely over a spot. To furnish a systematic variation of control sensitivity, control power, and damping, a total of nine combinations of control power and damping were rated by the pilots for each of the three stick travels, unless the pilot felt a combination would give the vehicle an unacceptable

characteristic (> 6.5). These conditions covered, to the ability of the X-14A, a high-, medium-, and low-control power for each of a high, medium, and low damping.

During these tests with varying lateral control powers, the longitudinal and directional control characteristics were kept constant and at a satisfactory level (see ref. 3). The results presented here are based upon the flight performance of two NASA research pilots who have considerable experience in both helicopters and VTOL aircraft.

RESULTS AND DISCUSSION

In the evaluation of hovering and low-speed control requirements for a VTOL aircraft, two types of operation can be considered. These include (1) gross maneuvering where relatively large control inputs are used to provide rapid changes in aircraft position and (2) steady or precision flight where accuracy of aircraft position is important. It can be expected that maneuvering type flight will determine the total control power (maximum moment) required; however, the associated stick travel (sensitivity) must be suitable for all types of operation, including precision flying. These points are discussed in the following sections of the report.

Maneuvering Flight

The numerical pilot rating system shown in table I, and described in reference 4, was used by the pilots in rating the various characteristics. Each pilot rated three different amounts of control power at three levels of damping for each of the three stick travel ranges. The results are presented in table II and are also summarized on figure 2. The small circular symbol shows the control power and damping conditions being evaluated and the numbers within the larger symbols are the ratings the pilots assigned to that condition for each stick travel. The pilot rating boundaries of 3-1/2 and 6-1/2, as derived in the tests of reference 3, are included on this figure for reference. Examination of the pilots' ratings shows that over the range tested changes in stick gearing had only a small affect on the pilot's opinion of a given level of control power and damping. These pilot rating data indicate fair agreement between the two pilots. The larger discrepancies occurred in the values listed for the lowest rate damping conditions tested. This is probably because the pilot who assigned the lower numbers was extremely familiar with the vehicle's characteristics and appreciated the increased responsiveness at these low damping values. The other pilot being less familiar with the vehicle rated the control power and damping values more in line with the results of reference 3.

The data of table II have been plotted as a function of lateral control sensitivity on figure 3. On this figure, also, the numbers within the symbols indicate the pilot's rating for that particular set of conditions.

Since both the quantities which govern sensitivity, that is, total control power and stick travel, were changed, it was possible for the pilot to rate the same sensitivity with two different total control powers. The pilot's desire for control power rather than sensitivity is illustrated by the lack of uniform variation of pilot's opinion as sensitivity was changed. It will be seen that in the areas of nearly the same sensitivity with different control powers the pilot rated the higher control power superior (lower pilot rating number). To obtain the higher sensitivities with low control powers it was necessary to use small amounts of stick travel; thus, the pilot continually hit the stops during maneuvering flight. The fact that the stick hit the stops during this control activity quickly informed the pilot that he had used maximum available control and he tended to downgrade this condition.

Further comparison of the pilot's rating of control power or sensitivity is shown in figure 4. These data are from table II for a damping of 1.75 per sec. This figure shows that at a given level of control power, variations in sensitivity have little affect on the pilot's rating. However, the pilot's ratings showed considerable change when the sensitivity was constant and the control power varied. Also shown on this figure are the ratings for pilot B, obtained from a similar study conducted in a variable-stability and control helicopter.¹ The characteristics of this helicopter and its "model" variable-stability system are discussed in reference 5. The pilot's desire for increased control power rather than increased sensitivity is also shown by the helicopter results. The relative levels of control power for satisfactory rating (PR = 3.5) for the helicopter is considerably less than that for the X-14A. The reason for this is unknown. Possible reasons for this discrepancy may be a leading lateral acceleration from the rapid-responsive rotor-plane rotation, or due to the model technique used to compute the variable-stability inputs cancelling all gust and extraneous inputs.

Steady Hovering

It had been expected that increased sensitivity, greater than that normally used in the X-14A, would be helpful during a steady hovering task in that the magnitude of stick motion and therefore the pilot's work load required to remain over a spot would be reduced. To investigate this, the pilots were asked to evaluate the various stick travel and control power characteristics used in this study, in light of their ability to maintain the vehicle hovering over a spot. The pilots felt that the increased sensitivity was beneficial during steady hovering, but the X-14A, which is not self-disturbing during hover, could be successfully hovered over a spot using a small fraction of the control power required for maneuvers. The increased sensitivity would be more beneficial in a hovering vehicle with self-disturbing tendencies where the pilot's work load would be decreased as a result of having to supply smaller movements of the stick to control the upsetting moments.

¹A more detailed accounting of the study in the variable-stability helicopter at Langley Research Center will be published by John F. Garren and James R. Kelley.

CONCLUDING REMARKS

Flight tests of a hovering VTOL aircraft with varying amounts of control power and stick travel indicated that the pilots' opinions of the maneuvering requirement were predominantly influenced by total control power available and that changing the stick travel over the range tested had only a minor effect. During steady hovering, the increased sensitivity reduced the pilot's work load, thus, it would be more favorable.

Ames Research Center

National Aeronautics and Space Administration

Moffett Field, Calif., Nov. 30, 1964

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2. Salmirs, Seymour, and Tapscott, Robert J.: The Effects of Various Combinations of Damping and Control Power on Helicopter Handling Qualities During Both Instrument and Visual Flight. NASA TN D-58, 1959.
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4. Cooper, George E.: Understanding and Interpreting Pilot Opinion. Aero. Eng. Rev., vol. 16, no. 3, Mar. 1957, pp. 47-51, 56.
5. Garren, John F., Jr., and Kelly, James R.: Description of an Analog Computer Approach to V/STOL Simulation Employing a Variable Stability Helicopter. NASA TN D-1970, 1964.

TABLE I.- PILOT OPINION RATING SCHEDULE

	Adjective rating	Numerical rating	Description	Primary mission accomplished	Can be landed
Normal operation	Satisfactory	1	Excellent, includes optimum	Yes	Yes
		2	Good, pleasant to fly	Yes	Yes
		3	Satisfactory, but with some mildly unpleasant characteristics	Yes	Yes
Emergency operation	Unsatisfactory	4	Acceptable, but with unpleasant characteristics	Yes	Yes
		5	Unacceptable for normal operation	Doubtful	Yes
		6	Acceptable for emergency condition only ¹	Doubtful	Yes
No operation	Unacceptable	7	Unacceptable even for emergency condition ¹	No	Doubtful
		8	Unacceptable - dangerous	No	No
		9	Unacceptable - uncontrollable	No	No

¹Failure of a stability augments

TABLE II.- PILOT RATING LATERAL SENSITIVITY

Control power, radians/sec ²										
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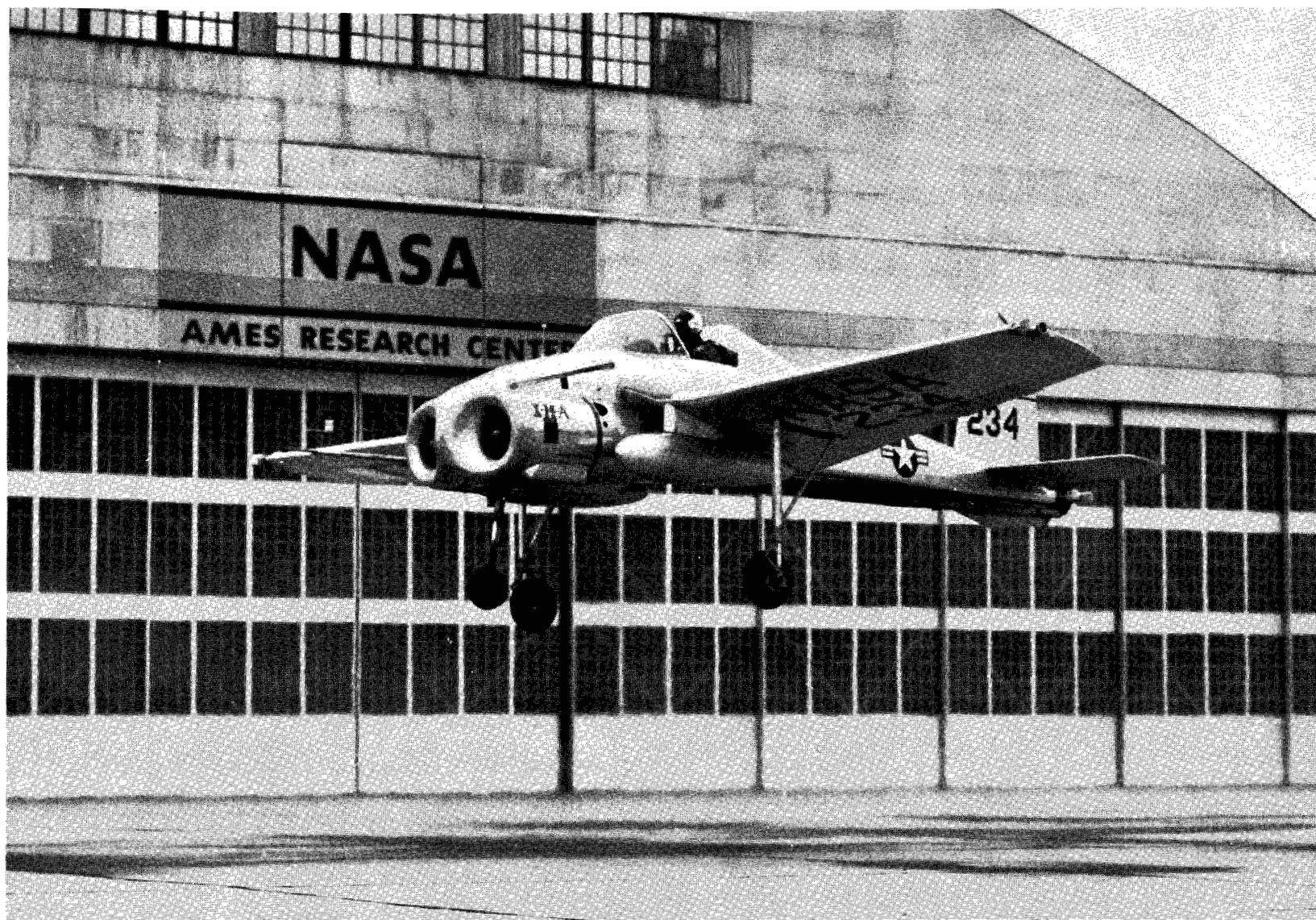


Figure 1.- Photograph of test aircraft in hovering flight

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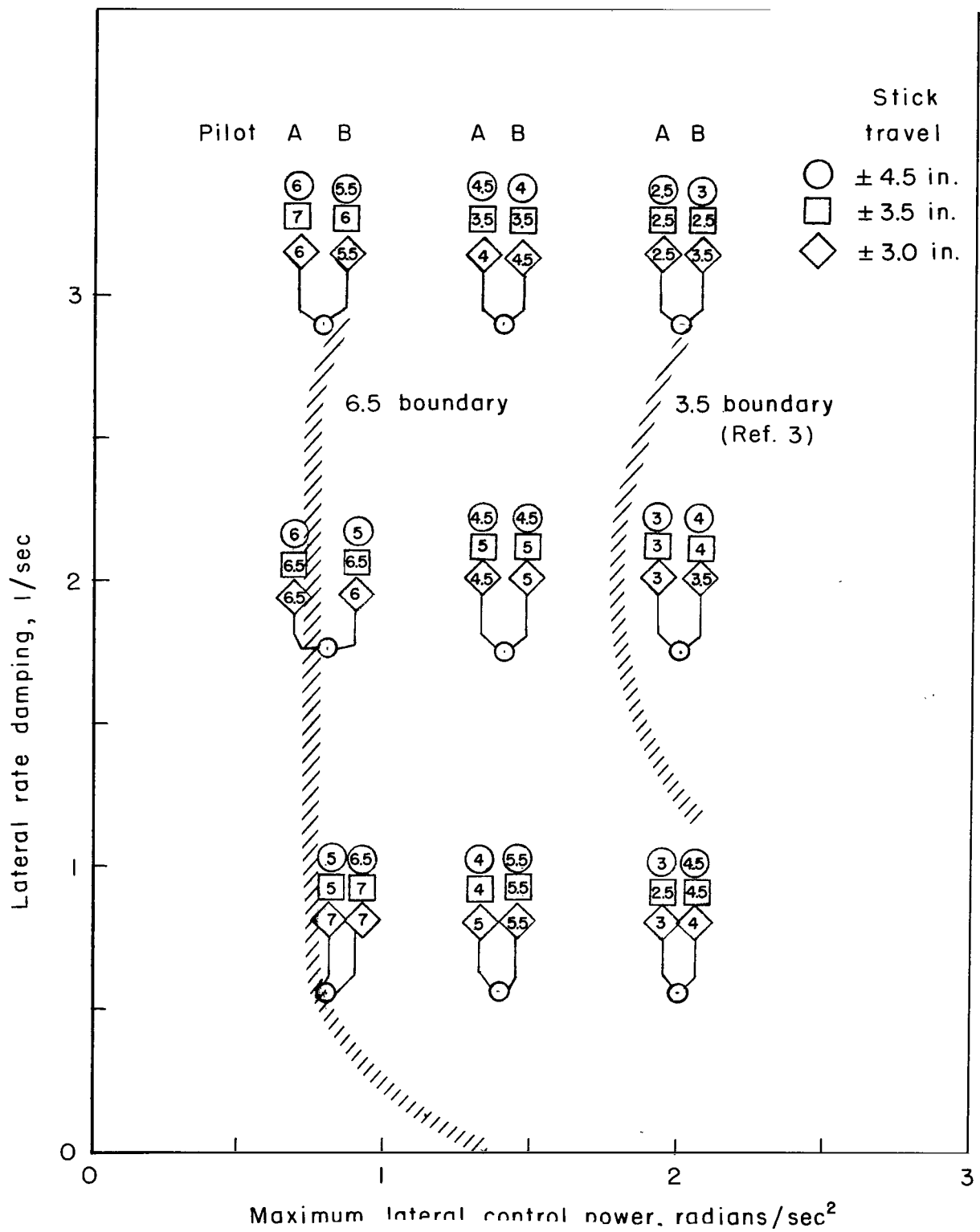


Figure 2.- Summary of the pilots' rating of the lateral control characteristics.

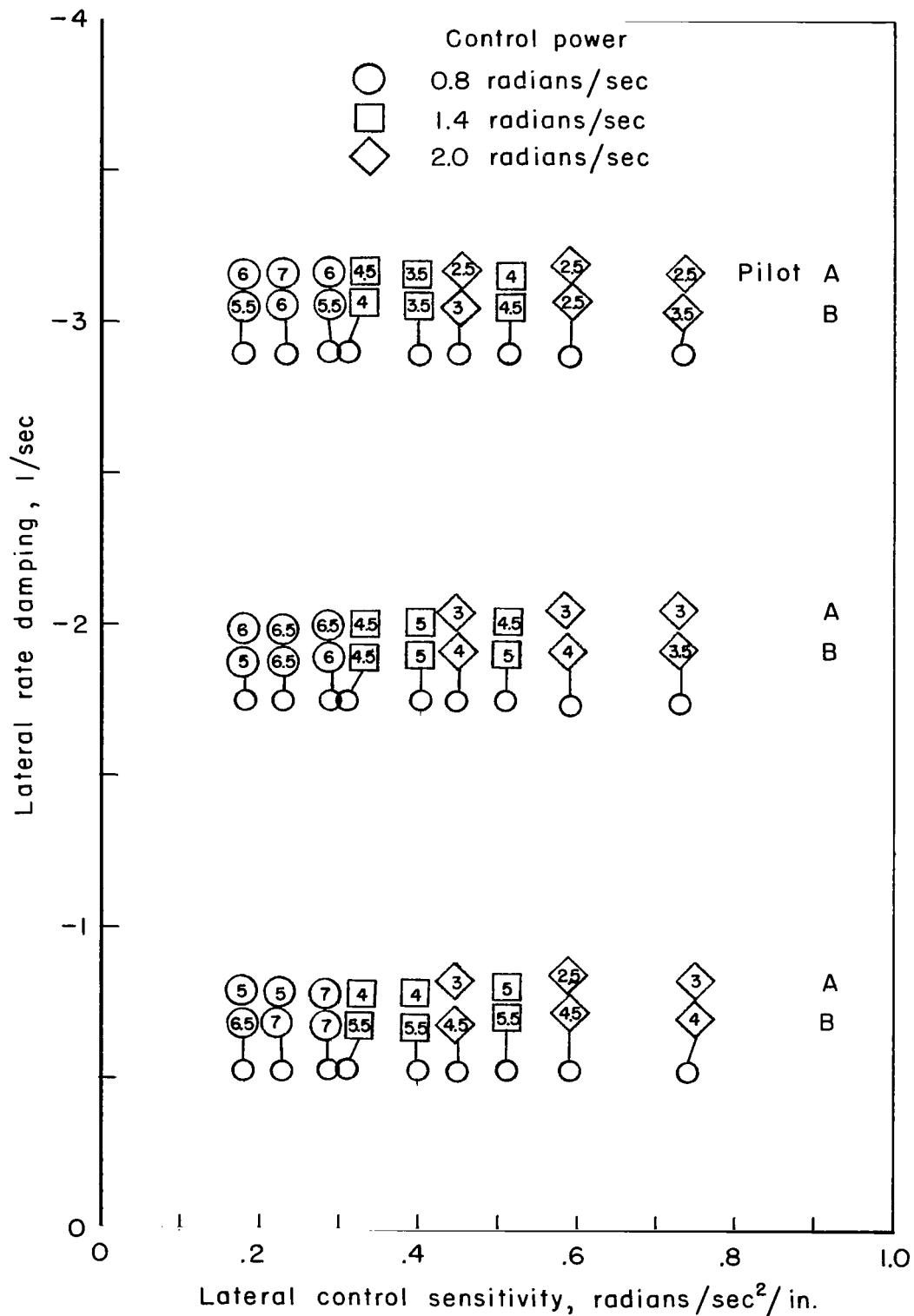


Figure 3.- Pilots' rating of the lateral control sensitivity.

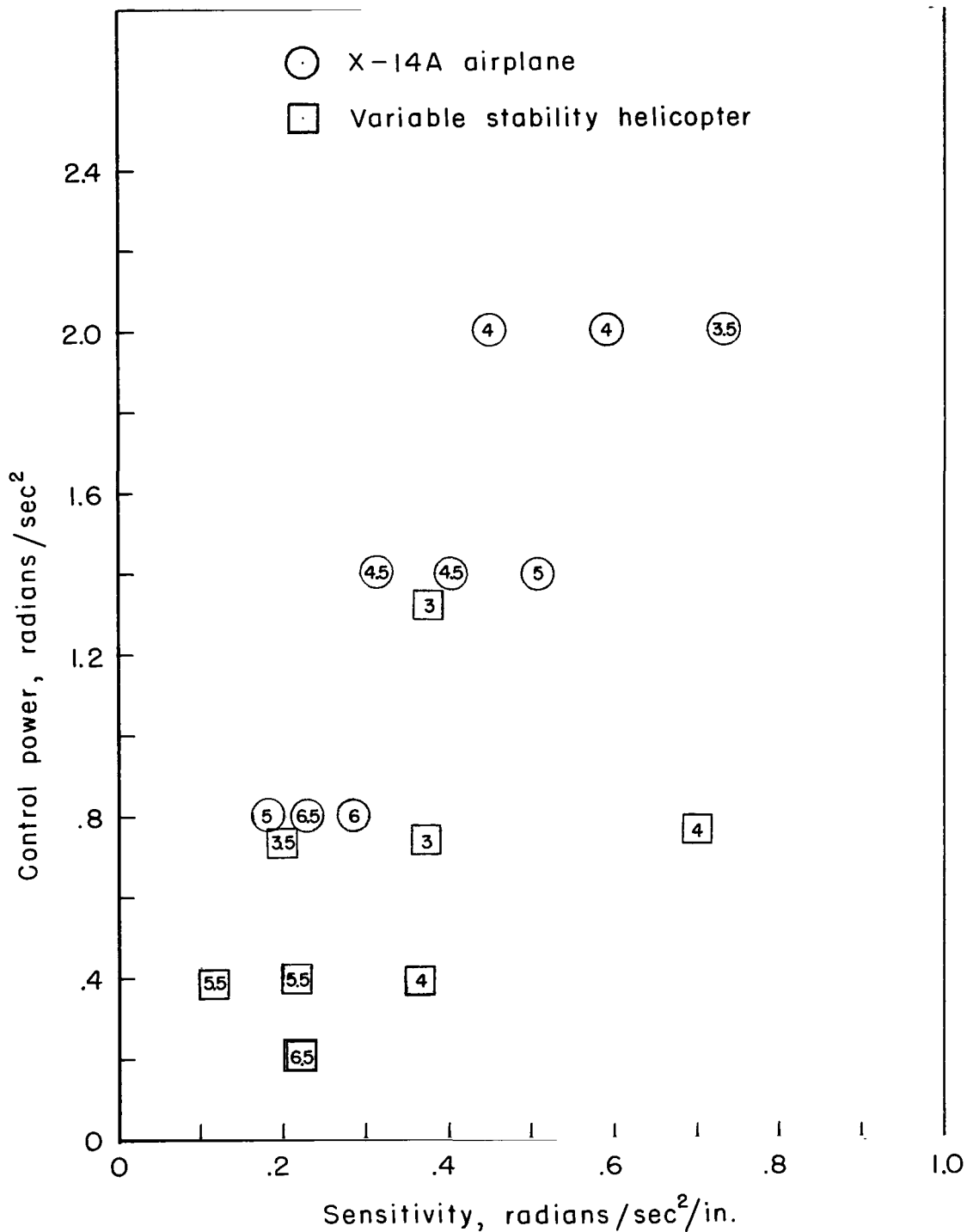


Figure 4.- Comparison of pilots' ratings for control power and sensitivity; X-14A and variable stability helicopter, pilot B.

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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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